submitted version of article published in:
NorCal SETAC News 14(1):5-15, Feb 2003
(available: http://www.norcalsetac.org/news/news.htm and
http://www.epa.gov/nerlesd1/chemistry/pharma/overview.htm).

Pollution from the Combined Activities, Actions, and Behaviors of the Public: Pharmaceuticals and Personal Care Products

Christian G. Daughton, PH.D.

Chief, Environmental Chemistry Branch, ESD/NERL, Office of Research and Development,
U.S. Environmental Protection Agency, 944 East Harmon, Las Vegas, NV 89119
daughton.christian@epa.gov; 702-798-2207; fax 702-798-2142

Paint-by-number pictures of environmental pollution have long been envisioned by the laity — pollution created by the broad brush of dreary industry smokestacks and pipelines carrying liquids of unknown origin. While these stereotyped images may have faded with the implementation of numerous environmental regulations, and while pollution is now more surreptitious, the perception persists nonetheless that it's "them" rather than "me" behind whatever forms of pollution remain. The realization that pollution can result from the combined activities, actions, and behaviors of multitudes of individuals has really only been appreciated by the public with more obvious forms of pollution such as smog and litter. That more subtle forms of pollution emanate from the actions, activities, and behaviors of each individual has remained relatively obscure. A more accurate rendition of pollution is painted with many small brushes at the intricate interfaces in the interplay of industry and the individual — via consumerism — leading to a complex mixture of countless point- and dispersed-source origins.

This paper touches on a variety of issues involving chemical pollution that can result from the multitudes of consumer end-uses for a vast armamentarium of pharmaceuticals and personal care products (PPCPs). More specifically, this paper outlines some of the more important as well as the less appreciated aspects of this many-faceted, multidimensioned "emerging" issue.

The U.S. Environmental Protection Agency's Office of Research and Development (ORD) attempted to foster attention to this topic beginning in 1999, first with a critical review article (Daughton and Ternes 1999), followed by the first full-day conference session in North America (ACS 2000) and an accompanying book (Daughton and Jones-Lepp 2001). ORD's four-fold objectives in its efforts have been to: (i) Identify potential (future) environmental concerns (anticipatory research and identification of "emerging" issues, especially to identify pivotal sources of uncertainty that might affect risk estimates), (ii) Be proactive versus reactive (allowing for pollution prevention versus remediation/restoration; identify and foster investigation of “hidden” or potential environmental issues/concerns before they become critical ecological or human health problems), (iii) Foster interdisciplinary research, collaboration, and debate (catalyze research by academe, private sector, and government, both nationally and internationally, and to further the scientific dialog and debate needed to determine the relative importance of the topic with respect to overall environmental pollution), and ultimately (iv) Rule-in or rule-out those individual aspects of the overall issue that might need concerted attention (as a basis for any future informed rule making; to ensure that sound science serves as the basis for any eventual decisions for guidance or regulation).

As part of ORD's efforts with PPCPs as environmental pollutants, a comprehensive web site was conceptualized and implemented (beginning in April 2000). This web site (*http://www.epa.gov/nerlesd1/chemistry/pharma/index.htm*) is in a continual state of expansion and welcomes new materials, whether they are documents published in the literature (see: *http://www.epa.gov/nerlesd1/chemistry/ppcp/reference.htm*), notices of future conferences and

presentations made at completed conferences (*http://www.epa.gov/nerlesd1/chemistry/ppcp/conference.htm*), grants received (*http://www.epa.gov/nerlesd1/chemistry/pharma/grants.htm*), contact information for new researchers in the field to facilitate collaboration and communication (*http://www.epa.gov/nerlesd1/chemistry/pharma/images/scientists.pdf*), ideas regarding research needs and gaps (*http://www.epa.gov/nerlesd1/chemistry/pharma/needs.htm*), or any other information you would like to disseminate. Feel free to send suggestions for new materials to *daughton.christian@epa.gov*.

Beyond the focus on the scientific community, a major objective of the PPCPs web site has been to enhance the public's (e.g., see: *http://www.epa.gov/nerlesd1/chemistry/pharma/teaching.htm*) and the news media's (*http://www.epa.gov/nerlesd1/chemistry/ppcp/media.htm*) overall awareness and understanding of the origins of chemical pollution and their individual roles in its causes and prevention.

Scope of Issue: The scope of ORD's work with PPCPs encompasses the Environmental Ubiety, Ubiquity, Significance, Solutions, and Stewardship of Personal-Practices Pollutants (those chemicals used for Maintaining, Aiding, Enhancing, or Altering ... Therapy, Diagnosis, Appearance, Performance, Development, Perception, or Lifestyle ... or Preventing or Curing Disease) as a result of their purposeful and unintended/unavoidable collective discharge to the environment by humans as well as animals.

PPCPs are a diverse group of chemicals comprising all human and veterinary drugs (available by prescription or over-the-counter; including the newer genre of “biologics”), diagnostic agents (e.g., X-ray contrast media), “nutraceuticals” (bioactive food supplements such as huperzine A), and other consumer chemicals, such as fragrances (e.g., synthetic musks) and sun-screen agents (e.g., methylbenzylidene camphor); also included are “excipients” (so-called “inert” ingredients used in PPCP manufacturing and formulation). Many drugs are designed to elicit a wide range of therapeutic endpoints at low physiological doses (e.g., micrograms per kilogram); some can elicit effects at levels as low as nanograms per kilogram). Most have ill-defined biochemical mechanisms of action, and many interact with multiple non-therapeutic receptors (this "promiscuous" ligand-receptor activity can lead to non-therapeutic, unpredicted, adverse side effects).

It is important to keep in mind that PPCPs, while comprising myriads of unregulated chemicals from a multitude of chemical and therapeutic classes, represent but an unknown (and perhaps small) portion of the larger universe of chemical stressors that occur in the environment, including anthropogenic and naturally occurring toxicants.

Some Acronym History: The acronym "PPCPs" was coined merely as a shorthand convenience for the critical review article published in *Environmental Health Perspectives* (Daughton and Ternes 1999). Other related acronyms and terms have since appeared in the literature. One example is "PhACs" ("Pharmaceutically Active Compounds", coined by Sedlak et al. 2000), which encompasses therapeutically active drugs, but excludes non-therapeutic pharmaceuticals (e.g., diagnostic agents, X-Ray contrast media being two examples), as well as personal care products (synthetic musks and sunscreen agents are two examples). Another expression that aptly captures the pollution aspect of PPCPs is "feral pharmaceuticals," a term recently coined by Fisher and Borland (2003).

Sources and Origins of PPCPs in the Environment: The scope of this issue does NOT include the release of PPCPs or synthesis by-products from manufacturing processes, which has long been regulated. The origins of PPCPs as "trace" environmental pollutants (at ng-µg/L concentrations in waters) results largely from their worldwide, continual usage by humans and domestic animals as a result of

ingestion/excretion as well as the purposeful, direct disposal of expired or unwanted PPCPs (e.g., to sewage and landfills). Other potential routes to the environment include leaching from municipal landfills, runoff from confined animal feeding operations (CAFOs) and medicated pet excreta, loss from aquaculture, spray-drift from agriculture (e.g., antibiotics), direct discharge of raw sewage (storm overflow events and residential "straight piping"), sewage discharge from cruise ships (millions of passengers per year), oral contraceptives used as soil amendment and plant growth tonic (an ethnic urban legend), and transgenic production of proteinaceous therapeutics by genetically altered plants (aka plant-made pharmaceuticals [PMPs] from "molecular farming" or "biopharming"; see: *http://www.epa.gov/nerlesd1/chemistry/ppcp/relevant.htm#MolecularFarming*); some PPCPs are also directly discharged to the environment via dislodgement/washing of externally applied materials (such as topical medicaments and most personal care products). The sources and origins of PPCPs as environmental pollutants have been captured in a "cartoon" format designed for public outreach and student/teacher use and is freely available from the PPCPs web site (*http://www.epa.gov/nerlesd1/chemistry/pharma/images/drawing.pdf*).

Overviews: The many aspects of this emerging issue have been summarized in a number of review articles and book chapters. Most of the major works as well as summaries of the overarching issues have been captured in a series of articles, some of which are available directly from the PPCPs web site (*http://www.epa.gov/nerlesd1/chemistry/pharma/new.htm*); these include Daughton and Ternes (1999), Daughton and Jones-Lepp (2001), Kümmerer (2001), and a slideshow presentation (*http://www.epa.gov/nerlesd1/chemistry/pharma/slides/home.htm*). The better-delineated aspects covered in these works will not be reiterated here. Instead, attention will be devoted to some of those facets that have received comparatively less attention.

Other Views

The remainder of this brief overview offers what might prove to be some controversial viewpoints or perspectives on several fronts in the hope of furthering discussion or debate amongst environmental scientists.

The Universe of Chemical Pollutants: PPCPs are but one diverse galaxy of potential pollutants amidst the larger universe of chemical stressors. Determining the identities, amounts, prevalence, and distributions of pollutants in the environment resides in the domain of analytical chemistry. Environmental scientists have devoted most of their focus for decades on but a small subset of chemical stressors in the environment. Since the 1970s, the impact of chemical pollution has focused almost exclusively on conventional "priority pollutants," especially on those collectively referred to as "persistent, bioaccumulative, toxic" (PBT) pollutants, "persistent organic pollutants" (POPs), or "bioaccumulative chemicals of concern" (BCCs). The "dirty dozen" is a ubiquitous, notorious subset of these, comprising highly halogenated organics (e.g., DDT, PCBs). It is important to recognize that the current "lists" of priority pollutants were primarily established in the 1970's in large part for expediency — that is, they could be measured at comparatively low levels with off-the-shelf chemical analysis technology. Priority pollutants were NOT necessarily selected solely on the basis of risk, nor did they represent the only chemicals posing ecological or human health risks. The conventional priority pollutants represent only one piece of larger risk puzzle — one of largely unknown scope.

An Alternate Perspective of the Risk Universe: Conventional, regulated pollutants are monitored using a target-based approach (using a list of preselected compounds). This approach necessarily overlooks an undefined portion of other toxicants that play a role of unknown magnitude and significance in the totality of ecological or human exposure. Analytical chemistry dictates the boundaries of the exposure

envelope that are explorable — it defines those areas of the envelope that can and can not be examined (see "The Critical Role of Analytical Chemistry": *http://www.epa.gov/nerlesd1/chemistry/pharma/critical.htm*; in particular, see the illustrations Figures 1-4). With regard to the prevalence of xenobiotic occurrence in the environment, some possible generalizations can be set forth regarding their ubiquity:

- Xenobiotics comprise both anthropogenic chemicals and those that occur naturally
- Toxicity can be associated with both broad classes
- Some anthropogenic chemicals (even many organohalogens) also have natural sources
- Environmental prevalence is a function of both occurrence frequency and concentration
- Few xenobiotics occur at higher concentrations (e.g., parts per million: ppm)
- Many xenobiotics occur at low concentrations (e.g., parts per billion to trillion: ppb-ppt; nanomolar to picomolar: nM-pM)
- Perhaps most occur at still lower concentrations (e.g., femtomolar to attomolar, fM-aM)
- The lower the concentration, the higher the probability of larger numbers of distinct chemicals occurring
- Exponentially more types of chemicals occur at exponentially lower concentrations (here one can ask "does the distribution of chemical types versus their concentrations follow a power law, as shown for such a wide array of other phenomena?" e.g., see: Buchanan 2000); this phenomenon is illustrated in Figure 4 at *http://www.epa.gov/nerlesd1/chemistry/pharma/critical.htm*.
- At the very lowest concentrations (zeptomolar to yoctomolar, zM-yM), the off-the-cuff truism that analytical chemists are fond of may apply:

"Everything can be found everywhere".

With respect to which xenobiotics are valued by toxicologists and therefore monitored in the environment, a quote often attributed to Einstein comes into play:

> "Not everything that can be counted counts, and not everything that counts can be counted."

This perspective can be converted to a possible corollary relevant to environmental monitoring:

> "Not everything that can be measured is worth measuring, and not everything worth measuring is measurable."

This corollary could be seen as leading to some additional truisms regarding monitoring for environmental pollutants:

- What one finds usually depends on what one aims to search for.
- Only those compounds targeted for monitoring have the potential for being identified and quantified.
- Those compounds not targeted will elude detection.
- The spectrum of pollutants identified in a sample represent but a portion of those present and they are of unknown overall risk significance.

Caveats Regarding Chemical Analysis: The focus to date on monitoring for PPCPs in the environment has centered on dissolved concentrations in waters. This focus results from the generally higher aqueous solubilities of drugs compared with most regulated pollutants. To avoid a potentially biased focus on water columns, however, it is important to keep in mind some alternative environmental compartments. Measurement of dissolved water concentrations of parent chemicals could potentially mislead by yielding

underestimates of total environmental loads. Hidden "reservoirs" (compartments not accounted for by water analysis) of parent toxicant can result in:

- hydrolysis of excreted conjugates, leading to reconversion back to parent forms
- desorption from sediments/suspended particulates or from separate phases such as mono-molecular interfacial films
- dissolution of poorly soluble forms (e.g., divalent cations-tetracycline)
- unsuspected environmental compartments, such as conveyance to land via sewage biosolids
- biased analytical methodologies (especially during sample preparation and extraction; leading for example to low, uncorrectable analytical recoveries)
- calculating total environmental loads via aqueous-dissolved quantities that yield estimates of total load or burden that are biased orders of magnitude too low.

Caveats Regarding Exposure: The reality of exposure is reflected by the comprehensiveness of chemical measurements. Dissolved concentrations (or even total solids loadings) may not represent actual exposure concentrations in certain scenarios, such as for microorganisms (extremely important with regard to assessment of antibiotic exposure and selection of resistance) or benthic organisms. In microbial settings, much happens in the microenvironment of interfaces. Interface chemistry does not necessarily reflect dissolved chemistry. "Concentrations" of stressors can be substantially higher at an interface (for example, the surface where a biofilm might establish). The consequences of heterogeneous distribution could be profound. For example, bacteria could be exposed to higher concentrations of antibiotics than projected from water concentrations, perhaps high enough to select for resistance or alter community species structure (see: *http://www.epa.gov/nerlesd1/chemistry/pharma/images/nas-iom.pdf*).

Caveats Regarding Toxicology: A critical issue with respect to PPCPs, which occur in the environment at concentrations far below levels ascribed to "therapeutic" levels, is that of long-term, continual simultaneous exposure to multiple toxicants. Hazard assessment based on hypothetical exposure to single substances in isolation from all others is undoubtedly never reflected in the real world. Assessment of risk on the basis of a substance in isolation from the complete exposure envelope fails to factor in or account for:

- Exposure "Trajectory" (prior exposure history, vulnerability; sequelae are but one common example of outcomes from prior exposure)
- Interactions from other stressors of similar/dissimilar mechanisms of action (MOAs) or higher-level endpoints
- Potentiation or sensitization by chemicals not toxic by themselves (e.g., efflux pump inhibitors or inducers of cellular stress response)
- Subtle effects capable of escaping immediate notice. This concern served as a premise of the paper by Daughton and Ternes (1999). Behavioral effects are but one example, and certain drugs are already known to have the potential to profoundly alter behavior in aquatic organisms. The next generation of toxicity screening methods need to accommodate a wider spectrum of subtle effects. An interesting aside in human history shows a parallel in the hypothesis of subtle effects. A practice popular and even fashionable in Europe from the early to late 1600s – with a resurgence in the 1800s – was incremental poisoning of spouses designed to appear "natural." "The atrocious system of poisoning, by poisons so slow in their operation, as to make the victim appear, to ordinary observers, as if dying from a gradual decay of nature, has been practised in all ages" (MacKay 1841).

These issues and others regarding the many aspects of exposure and stressors are captured in an experimental cartoon illustration further discussed below at "Public Outreach and Science Literacy."

Caveats Regarding Environmental Fate: Our conventional view of "persistence" relates to structural integrity of chemical structure and how refractory it is to alteration by biophysicochemical processes, keeping in mind that the major concern posed by persistence is the prolongation of the time over which exposure can occur. But exposure to a chemical stressor can be sustained in the absence of structural stability simply by the continual infusion of a chemical to the environment. This is how PPCPs tend to enter the environment in waters receiving the continual discharges from sewage treatment plants as well as the many sources of raw sewage. Chemicals continually infused to the aquatic environment essentially become "persistent" pollutants even if their half-lives are short — their supply is continually replenished (analogous to a bacterial chemostat; e.g., see: Daughton and Hsieh 1977). These can be referred to as pseudo-persistent chemicals (P2's).

Need for New Paradigm in Environmental Monitoring? There is a striking parallel between sources of exposure in human medicine and in the environment. The prescribing to a single patient by different physicians of multiple drugs (e.g., in geriatric medicine) all sharing a common mechanism of action (MOA) can lead to adverse drug reactions; a common example is the inadvertent over-prescribing of multiple drugs having anticholinergic activity. The analogous scenario may exist in the environment with respect to chemicals from a multitude of disparate or even similar chemical classes, all sharing the same MOA. This places into question the feasability of regulating individual chemicals, especially in a commerce such as with drugs (in contrast to pesticides) where current-generation therapeutic agents are quickly superceded by an ever-escalating procession of newer members and classes; with drugs, this is partly catalyzed by the "omics" revolution (from study of the genome, proteome, glycome, metabonome, etc.; see glossary at: *http://www.genomicglossaries.com/*). Because of the probability of discovery of newer targets and therefore development of drugs with new MOAs, it may therefore not prove feasible to focus assessments on individual drugs, other than perhaps as examples (surrogates) of larger classes. The actual MOAs (which are shared by many substances) — since they have permanence — may prove to be a more useful way to assess overall hazard.

Instead of monitoring on a chemical-by-chemical basis, it might make more sense to monitor for indicators of exposure or effect that reflect biologically important responses (efflux pump inhibition activity – critical to aquatic health in particular – is but one example). A monitored value for a response that approaches a set point would then trigger the need for chemical characterization of the chemical constituents responsible for the activity. An analogy exists in analytical chemistry in the measurement of colligative properties that reflect, for example: all organic chemicals (with TOC as the colligative measure), all organohalogens as TOX, all organonitrogen compounds as TKN, all lipids as "oil and grease/TPH". Each of these colligative measures reflects the overall numbers of countless chemicals — all of which share a particular property. Such an approach to regulation would be based on specific biological MOAs, better reflecting the potential for cumulative effects.

Summary of Some Under-Appreciated Points Regarding Pharmaceuticals as Environmental Pollutants: Keeping in mind the caveats outlined above (and others mentioned in Daughton 2002), here are some points not frequently discussed:

- Therapeutic doses for individual drugs (which usually reflect exposures many orders of magnitude higher than those afforded by dissolved water concentrations) may not be relevant benchmarks against which to judge risk. This is because therapeutic endpoints are not necessarily the ones of concern for non-target organisms; drug receptor repertoires can differ from those for humans and other endpoints could come into play at lower concentrations.

- Current approach for assessing risk due to exposure to chemical stressors is performed out of context — in the absence of other chemical stressors (possessing similar and dissimilar modes of action) and without consideration of the exposure trajectory (e.g., prior exposure history). This limitation is particularly important with respect to (i) cumulative exposure to multiple chemicals sharing a like MOA (e.g., serotonin modulators, anticholinergics), (ii) potentiation or sensitization by chemicals that are not toxic by themselves (such as efflux pump inhibitors, initiators of the cellular stress response, and inhibitors/inducers of microsomal oxidases), and (iii) unique windows of vulnerability during exposure.

- Current ecological assessment approaches (e.g., conventional aquatic toxicity tests performed on single chemicals in isolation from others and out of context of a larger ecological structure) represent a reductionist approach that is only slowly yielding to the recognition of the importance of a holistic, "systems level" approach that encompasses a larger degree of complexity and interplay within and among organisms and populations.

- The emphasis with regard to environmental monitoring should perhaps not be placed on individual chemical stressors, but rather on evolutionarily conserved biological receptors or processes (e.g., efflux pumps, cellular stress response, cytochrome P450 systems). This would place the emphasis more on effects (and potential outcomes) rather than exposure. This would also eliminate the never-ending need to evaluate which of an ever-expanding universe of new consumer chemicals to target for regulatory monitoring; one would only need to be vigilant for the emergence of new MOAs that have come into play.

- Current environmental monitoring data targeted at PPCP concentrations dissolved in water could possibly underestimate environmental loads by unknown magnitudes for a variety of reasons (this is particularly relevant at least to antibiotic occurrence data). Significant reservoirs of PPCPs may exist in other environmental compartments, especially interfaces.

- Current knowledge regarding the melange of so-called "emerging" chemicals gives us the luxury of being watchful (proactive) or more cautious with regard to the future introduction to commerce of chemicals having new mechanisms of action or that add to the existing environmental burden of chemicals sharing a common MOA or end-point.

- The question must be asked whether an overarching stewardship program (encompassing all aspects of the healthcare industry) aimed at overall reduction in drug usage, recycling, and disposal could yield a larger reduction in potential human and ecological exposure for far less investment in R&D and end-of-pipe control technologies, and at the same time yield collateral benefits for consumer/public health.

Importance of Establishing a Nationwide Early-Warning Water-Monitoring Network: A nationwide water monitoring network for the early warning detection of all NEWLY present (truly emerging; e.g., see: Daughton 2001a) chemicals (including PPCPs) should be considered as a national priority. Such a network would be useful not just for detecting the emergence of new pollutants, it could also prove central to detecting emerging, but yet-to-be noticed trends in drug abuse and illicit drug use (Daughton 2001b) as well as the introduction of chemical sabotage agents (especially those not amenable to detection via biology-based screening systems, such as toxicants whose toxicity is expressed only after long delay).

Chemicals that have not previously existed in the environment, but which are just beginning to develop or "emerge," present unknown risks, an unknown fraction of which cannot be anticipated. The traditional approach to identifying and controlling chemical risks is reactive or retrospective. Environmental regulators have traditionally approached chemical pollution by devoting resources solely to managing established, well-characterized risks — e.g., the "list-based", target-analyte approach. A proactive approach is needed to prevent the establishment of new risks so that their subsequent management would not be needed. New and unanticipated chemicals (together with their transformation products) that have not previously occurred in the environment need to be identified as early as possible — well before their becoming pervasive in the environment. This necessitates a far more difficult approach — one for NON-target analysis.

One such non-target approach ("Pollutant Fingerprint Anomalies", C.G. Daughton, 29 August 2001; *http://www.epa.gov/nerlesd1/chemistry/pharma/science-issues.htm#One Proposal*) would be based on "change detection," where a repertoire of highly reproducible chromatographic/electrophoretic separations methods coupled with a sensitive, universal detector (e.g., any of various mass spectrometric formats or evaporative light-scattering) would be developed. Aqueous samples from nation-wide locations (representative of urban, rural, and pristine areas) would be periodically or continuously screened for the presence of any NEW constituent or abnormal relative abundances – ignoring all those constituents that are normally present (a type of "chemical amnesty" for the purposes of focusing resources on new pollutants). Such an approach would require sample-concentration schemes capable of multi-orders-of-magnitude "enrichment" of solutes, regardless of their polarities. The organic constituents in the resulting extracts would then be subjected to appropriate separation schemes, yielding reproducible "fingerprints" that reflect the compounds present and their relative abundances. Anomalies or changes in established fingerprints would trigger further investigation.

Minimization of Exposure: Regardless of the risks that the existing generation of PPCPs may or may not be proven to pose, the Precautionary Principle (*http://www.epa.gov/nerlesd1/chemistry/ppcp/relevant.htm#ThePrecautionaryPrinciple*) can be used as a guide to minimize future exposure to this ever-changing galaxy of bioactive substances. While end-of-pipe source control is an obvious means to reducing the introduction of PPCPs to the environment (such as by improving our decaying sewage and water distribution/treatment infrastructure), numerous other means can be employed for minimizing or preventing pollution. These reside in the arena of a prevention approach centered on a formalized environmental stewardship program. The many issues associated with such a program have been compiled for the first time — in a two-part paper that presents the background, rationale, and approach to "cradle-to-cradle" stewardship (Daughton 2003a,b). A distinguishing aspect of "cradle-to-cradle" stewardship programs is that benefits must accrue to all stakeholders. For a drug stewardship program, a wide range of benefits could result not just for the environment, but also for manufacturers/distributors, medical/healthcare industries, and the public consumer (patients). Medical outcomes can improve and healthcare monetary costs can be reduced while at the same time environmental exposure is lessened.

Risk Communication and Water Re-Use: In the context of overall risk, human exposure to PPCPs via drinking water is probably one of the lower-priority areas; focus should instead be devoted to the aquatic domain, where organisms can be subjected to continual multi-generational exposure. But this does not mean that human exposure to PPCPs is not an extremely important issue. This seeming contradiction is because the public perceives the presence of pollutants (especially those previously not known to occur and those whose origins largely trace directly to human or animal excreta) as posing imminent and significant risks to their health. The issues involved with the perception of risk (regardless of any real hazard that these chemicals may or may not pose) are among the more important that society faces today

and ones that will continue to grow in importance. Any work that can (i) better define the real hazards involved (if any — e.g., establish an absence of hazard) and (ii) better align public perceptions with those actual hazards, will prove extremely valuable, especially as fresh water resources continue to diminish and the pressure to re-use water grows. The communication of real hazard and its key importance to risk perception will prove critical to gaining public acceptance of the recycling of treated sewage for the direct or indirect replenishment (via groundwater recharge) of drinking water supplies ("toilet-to-tap" projects) — an issue of critical importance for the future of California and other arid areas. It is also one that faces numerous refractory barriers with regard to public acceptance. The proper communication of risk is so important that municipalities involved with water re-use efforts that will entail public exposure will discover the imperative to involve cognitive scientists such as psychologists and cultural anthropologists in central communication roles at the interface between their science-based message and the public. Failure to involve such communicators, especially in topics involving risk in the face of highly visible elements of uncertainty and emotion, will continue to doom well-planned, scientifically sound water re-use projects. The re-use of water for "banking" purposes can even prompt unanticipated perceived public backlash, one example being that the public could be given a false impression that enough water would be made available to sustain future urban growth (an argument that water banking causes unsustainable urban sprawl) (Fausset 2002).

Better communication of risk to the public as well as an improved reciprocal understanding by scientists of how the laity perceives risk, while an area that has received considerable attention by a number of scientists over the years (notable, seminal works on risk communication include those by Gerd Gigerenzer and Paul Slovic), is something that all of us as environmental scientists need to devote more attention to. The following brief news article (regardless of its factual accuracy) nonetheless illustrates the disconnect that has developed, especially with regard to risk:

> "The menu at the Coffee Garden at 900 East and 900 South in Salt Lake City has included a scrumptious selection of quiche for about 10 years. The recipe calls for four fresh eggs for each quiche. A Salt Lake County Health Department inspector paid a visit recently and pointed out that research by the Food and Drug Administration indicates that one in four eggs carries salmonella bacterium, so restaurants should never use more than three eggs when preparing quiche. The manager on duty wondered aloud if simply throwing out three eggs from each dozen and using the remaining nine in four-egg-quiches would serve the same purpose. The inspector wasn't sure, but she said she would research it." (Rolly and Jacobsen-Wells 2002).

Public Outreach and Science Literacy

The brief discussion above on communication of risk is a natural segue to the topic I would like to close with — an important topic that behooves each of us to adopt as an intimate part of our professional lives — public outreach and science literacy. Volumes have been written about the two intimately linked topics of communicating science (especially risk) and science literacy. With societies worldwide depending increasingly on rapid and complex advances in science and technology, arguments have long been made that optimal, rational sociopoliticoeconomic decisions cannot be made in democracies without a widespread public grounding in how science "works." The importance of understanding how science actually works (the processes by which it arrives at the knowable) rather than in what science has discovered or purportedly "knows" has been discussed by many. A recent brief discussion is given by Shermer (2002). Shermer emphasizes the need to instill the importance of HOW to think — HOW to go about the processes of discovery and forming THREADS and CONNECTIONS that come from the scientific process — rather than WHAT to commit to knowing (the facts of science). To further pursue this important debate, some pertinent resources are listed on one of the PPCPs web pages

("Communicating Science & Science Literacy": *http://www.epa.gov/nerlesd1/chemistry/pharma/comm.htm*); also of importance is the key role of the published literature (*http://www.epa.gov/nerlesd1/chemistry/forensics.htm*).

One of the major unanticipated outcomes from our work with PPCPs as pollutants has been the attention this topic has garnered from the public and media. I believe the reason for the public's interest derives from the ability of this topic to illustrate in a very literal, personal manner the public's inter-connectedness with the environment. The mere fact that PPCPs occur in the environment mirrors the intimate, inseparable, and immediate connection between the actions, activities, and behaviors of individuals and their environment, being that PPCPs owe their origins in the environment to their worldwide, universal, frequent, and highly dispersed but cumulative usage by multitudes of individuals.

The public's identification with this topic provides environmental scientists with a rare opportunity. It grants scientists an entree to connect with a receptive public and media and explore more deeply with them various principles of environmental science. Some other specific outcomes that could result from the development of various aspects of the topic include: (i) Recognition that POPs and PBTs represent only a portion of the overall environmental pollutant load. (ii) Showing the health benefits of minimizing overuse/misuse of drugs (e.g., antibiotics). (iii) Capitalizing on occurrence/effects issues to increase public understanding and appreciation for environmental science. (iv) Instilling with the public an understanding that the actions of the individual are tied directly to environmental consequences. (v) The feasibility of using non-intrusive drug monitoring of municipal sewage to raise community awareness of local usage patterns and trends (especially for illicit/abused drugs; see: Daughton 2001b), as well as to raise community awareness of inadvertent financial support to terrorism (Daughton 2001c).

One of the public outreach/teaching documents developed for our PPCPs project was the "cartoon" illustration "Origins and Fates of PPCPs in the Environment" (*http://www.epa.gov/nerlesd1/chemistry/pharma/images/drawing.pdf*). Experience gained from this graphic showed the power in using cartoons (which convey a sense of fun as opposed to work) to accomplish several purposes, including capturing the viewer's immediate attention and encouraging the exploration of concepts that might not otherwise ever be pursued. The illustration serves as a "hook" to get people more involved with science and to ask questions. It serves to communicate concepts that would otherwise receive only passing attention.

Many of the questions I receive from the public and media involve explaining various principles involved with toxicant exposure. An analogous illustration covering the many dimensions of exposure could prove useful. Using the same type of cartoon format, a prototype illustration was developed for the principles of exposure. The current version of this illustration is available at: *http://www.epa.gov/nerlesd1/chemistry/ppcp/stressors.htm*). It is mentioned here partly to solicit feedback or critique. Keep in mind that the audience for the illustration comprises teachers, students, journalists, public, and even scientists from other disciplines. This is a very wide spectrum and obviously the illustration cannot be all things to all people. The illustration attempts to capture many (but obviously not all) of the fundamental aspects of "holistic" exposure — which includes not just the immediate aspects of stressor-receptor relationships, but also the importance of time (history, or "trajectory"), duration, interactions, etc. The resulting illustration was purposefully made to look very busy. It violates many principles of graphic design because sometimes "busy" illustrations can better succeed in gaining and holding a reader's attention, especially students who are motivated by the unknown rewards of exploration. The hope is that illustrations such as this can at least be used by teachers to catalyze more involved discussions of toxicology (specifically, in this case, exposure). So feel free to send your comments (*daughton.christian@epa.gov*), and try and develop and share your own outreach materials.

REFERENCES

ACS. 2000. Pharmaceuticals and Personal Care Products in the Environment: An Emerging Concern. A symposium organized for the 219th National Meeting of the American Chemical Society, San Francisco, CA, 27 March 2000, by C.G. Daughton and T.A. Ternes (available: search for past meetings at: *http://www.chemistry.org/portal/PersonalScheduler/Welcome.jsp*; abstracts available: *http://www.epa.gov/nerlesd1/chemistry/ppcp/conference-past.htm*) [accessed 12 November 2002]

Buchanan M. 2000. Ubiquity. Crown Publishers.

Daughton CG. 2001a. 'Emerging' pollutants, and communicating the science of environmental chemistry and mass spectrometry – pharmaceuticals in the environment. *J Am Soc Mass Spectrom* 12(10):1067-1076 (available: *http://www.epa.gov/nerlesd1/chemistry/pharma/images/book_jasma.pdf*) [accessed 12 November 2002].

Daughton CG. 2001b. "Illicit drugs in municipal sewage: proposed new non-intrusive tool to heighten public awareness of societal use of illicit/abused drugs and their potential for ecological consequences" in Pharmaceuticals and Personal Care Products in the Environment: Scientific and Regulatory Issues (Daughton CG, Jones-Lepp T, eds), Symposium Series 791. Washington DC:American Chemical Society (available: *http://www.epa.gov/nerlesd1/chemistry/pharma/book-conclude.htm*) [accessed 12 November 2002].

Daughton CG. 2001c. A tool for public education - societal drug abuse and its aiding of terrorism. A post publication commentary/epilog to Daughton 2001b, 23 October 2001 (available: *http://www.epa.gov/nerlesd1/chemistry/pharma/book-post.htm*) [accessed 12 November 2002].

Daughton CG. 2002. Environmental stewardship and drugs as pollutants. *Lancet* 360:1035-1036 (available: *http://www.epa.gov/nerlesd1/chemistry/pharma/images/lancet-final.pdf*) [accessed 12 November 2002].

Daughton CG. 2003a. Cradle-to-cradle stewardship of drugs for minimizing their environmental disposition while promoting human health — Part I: rationale and avenues toward a green pharmacy. *Environ Health Perspect.,* in press (available: *http://www.epa.gov/nerlesd1/chemistry/ppcp/greenpharmacy.htm/*).

Daughton CG. 2003b. Cradle-to-cradle stewardship of drugs for minimizing their environmental disposition while promoting human health — Part II: drug disposal, waste reduction, and future direction. *Environ Health Perspect.,* in press (available: *http://www.epa.gov/nerlesd1/chemistry/ppcp/greenpharmacy.htm/*).

Daughton CG, Hsieh DPH. 1977. Parathion utilization by bacterial symbionts in a chemostat. Appl Environ Microbiol 34:175-184.

Daughton CG, Ternes TA. 1999. Pharmaceuticals and personal care products in the environment: Agents of subtle change? *Environ Health Perspect* 107(suppl 6):907-938 (available: *http://www.epa.gov/nerlesd1/chemistry/ppcp/images/errata.pdf*) [accessed 12 November 2002].

Daughton CG, Jones-Lepp T, eds. 2001. Pharmaceuticals and Personal Care Products in the Environment: Scientific and Regulatory Issues. Symposium Series 791. Washington DC:American Chemical Society, 416 pp. (available: *http://www.epa.gov/nerlesd1/chemistry/pharma/book.htm*) [accessed 12 November 2002].

Fausset R. 2002. Environmentalists File lawsuit to block 'water banking' plan. LATimes.com, 8 Nov 2002.

Fisher PMJ, Borland R. 2003. Gauging the pharmaceutical burden on Sydney's environment: a preventative response. *J Cleaner Production* 11(3):315-320

Kümmerer K (ed.) 2001. Pharmaceuticals in the Environment: Sources, Fate, Effects and Risks. Springer-Verlag. ISBN: 3-540-41067-8 [contents available at: *http://www.epa.gov/nerlesd1/chemistry/pharma/kummer/default.htm*] [accessed 12 November 2002].

MacKay C. 1841. "The Slow Poisoners," in Extraordinary Popular Delusions and the Madness of Crowds (available: *http://www.litrix.com/madraven/madne001.htm*; *http://www.litrix.com/madraven/madne016.htm*) [accessed 12 November 2002].

Rolly P, Jacobsen-Wells J. 2002. Rolly & Wells: Bureaucrat's math makes dizzy dozen. *The Salt Lake Tribune,* 11 October 2002.

Sedlak DL, Gray JL, Pinkston KE. 2000. Understanding micro contaminants in recycled water. *Environ Sci Technol* 34(23):509A-515A.

Shermer M. 2002. Smart people believe weird things: rarely does anyone weigh facts before deciding what to believe. *ScientificAmerican.com*, September 2002 (available: *http://www.sciam.com/article.cfm?articleID=0002F4E6-8CF7-1D49-90FB809EC5880000&catID=2*) [accessed 12 November 2002].